Scaffolding digital game-based learning in primary mathematics classrooms

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Abstract

The present study explores approaches to teacher scaffolding in digital game-based learning in primary mathematics classrooms as well as the effects on students' perceptions of learning in a digital game in which scaffolding was provided. A total of 141 primary school students and four mathematics teachers participated in the experiment, and qualitative data were collected through classroom observation and student interviews. The results identified whole-class and one-to-one scaffolding strategies, both of which had an important effect on students' learning activities in the context of digital games in mathematics in primary education.

Keywords scaffolding; digital game-based learning; mathematics; primary education.

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Keywords: scaffolding, digital game-based learning, mathematics, primary education

1. Introduction

Teachers play a key role in digital game-based learning, which can be beneficial to students in primary education (Chen & Law, 2016; Author, 2018; Haataja et al., 2019). Several studies have indicated that students need teacher scaffolding to solve problems and build connections between subject knowledge and the knowledge learned in digital games (Chen & Law, 2016; Haataja et al., 2019; Pata, Sarapuu, & Lehtinen, 2005). However, according to Barzilai and Blau (2014, p. 65), integrating teacher scaffolding into gameplay can "negatively impact learners' perceptions of learning and enjoyment in the game." Therefore, it is crucial to understand and design appropriate teacher scaffolding in the digital game-based learning environment so that students' learning achievement and engagement can be influenced in a positive manner (Barzilai & Blau, 2014; Chen & Law, 2016; Pata et al., 2005; Rienties, et al., 2012). In this study, we proceed to explore approaches to teacher scaffolding in a primary mathematics digital game in order to solve arithmetic problems as well as the effects on students' perceptions of learning in a digital game in which teacher scaffolding was provided.

1.1. Scaffolding

Scaffolding was introduced by Wood, Bruner, and Ross (1976) as tutoring or assistance that "enable[s] a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" (p. 90). According to Makar, Bakker, and Ben-Zvi (2015), scaffolding is temporary support supplied by a teacher or knowledgeable person to help students solve problems that they are unable to solve independently. This support can be offered in different ways, for example, modeling, posing questions, etc. (Van de Pol, Volman, & Beishuizen, 2010). Research on scaffolding generally focuses on one-to-one or small-group tutoring, and the teacher plays an important role in the scaffolding process by providing adaptive and in-time support that improves students' learning processes (Chen & Law, 2016; Makar et al., 2015; Muhonen, Rasku-Puttonen, Pakarinen, & Poikkeus, 2016; Wood et al., 1976).

Tropper, Leiss, and Hänze (2015) suggested that the scaffolding process involves three steps: 1) *contingency*, which includes responsive, adaptive, and in-time support for students' current performance; 2) *fading*, which refers to the gradual withdrawal and a decrease in support following improvement in students' performance and capacity; and 3) *the transfer of responsibility*, which means that the responsibility of the learning process is transferred from the teacher to the students. These three steps are closely interconnected. When contingent support is provided by teachers and results in improved student understanding and performance, support can then be withdrawn and decreased; subsequently, the fading of support leads to a responsibility shift from the teacher to the students so that students can regulate and conduct their learning independently (Muhonen et al., 2016; Pata et al., 2005; Tropper et al., 2015; Van de Pol et al., 2010).

According to Van de Pol et al. (2010), scaffolding is an interactive process between teachers and students, which requires active participation from both parties. Contingency is the first crucial step in the process of scaffolding. To provide adaptive support and intervention, an effective diagnosis of students' current levels of understanding is essential, and dialogue between teachers and students is a good tool to achieve this diagnosis (Muhonen et al., 2016; Pata et al., 2005; Tropper et al., 2015; Van de Pol et al., 2010). Muhonen et al. (2016) emphasized that dialogic interactions between teachers and students have an important effect on students' learning and development. Scaffolding through dialogue provides opportunities for students to present what they have not understood on their own while also stimulating and developing their thinking and understanding (Makar et al., 2015; Muhonen et al., 2016; Pata et al., 2005).

1.2. Digital game-based learning in mathematics

Mathematics is a core discipline. It provides practical knowledge for daily life and plays an important role in personal development (Huang, Huang, & Wu, 2014; Author, 2015a). However, mathematics is often a discouraging subject for many students in primary and secondary education. For example, Luhan, Novotna, and Kriz (2013) showed that mathematics was often classified as an unfavorable course among students, since they saw it as dreary, difficult, and useless. Researchers have found that individuals who have trouble with mathematics learning could be at a disadvantage in terms of their career expectations and professional lives (Author, 2015a; Author, 2015b). Therefore, it is important to develop effective methods to increase students' interest in mathematics, improve their understanding of conceptual knowledge, and enable them to develop their arithmetic skills (Author, 2015a; Pope & Mangram, 2015).

The potential of digital game-based learning in education has been widely recognized for several decades (Nousiainen, Kangas, Rikala, & Vesisenaho, 2018; Chang et al., 2016; Iten & Petko, 2016). In mathematics education, digital game-based learning is considered a fundamental learning tool that can help students acquire conceptual knowledge, practice arithmetic skills, and facilitate their engagement in the classroom (Bakker, van den Heuvel-Panhuizen, & Robitzsch, 2016; Drijvers, Doorman, Kirschner, Hoogveld, & Boon, 2014; Meletiou-Mavrotheris & Prodromou, 2016). Digital games, which offer enjoyment and pleasure, may reduce students' anxiety and frustration and support mathematical development (Barkatsas, Kasimatis, & Gialamas, 2009; Chang et al., 2016; Huang et al., 2014; Author, 2015a; Pope & Mangram, 2015). Not only are digital games fun, interactive, and great at the prospect of immediate feedback, they also allow students to try tasks many times, even when making mistakes, giving them opportunities to participate and explore (Bakker et al., 2016; Chen & Law, 2016; Chen, Wong, & Wang, 2014; Huang et al., 2014; Iten & Petko, 2016; Watson, Mong, & Harris, 2011). It is believed that digital game-based learning can provide a context in which facilitate an increase in students' learning interest, improve their learning confidence, and enable a greater willingness to learn (Bakker et al., 2016; Chen et al., 2014; Huang et al., 2014; Iten & Petko, 2016; Author, 2017; Pope & Mangram, 2015).

1.3. Scaffolding in digital game-based learning

While digital game-based learning provides students with opportunities to explore and motivates them to learn in a different way, there are challenges to the use of digital games in learning. These include technological difficulties, behavioral regulation, emotional control, time management, combining these games within traditional classrooms, etc. (Chen & Law, 2016; Vandercruysse, Vandewaetere, Cornillie, & Clarebout, 2013; Watson et al., 2011). Despite the difficulties, many teachers and educational researchers see promise in the use of scaffolding in supplementing digital game-based learning so that it benefits students' understanding and deep learning (Barzilai & Blau, 2014; Chen & Law, 2016; Kangas, Kostinen, & Krokfors, 2017; Nousiainen et al., 2018; Waiyakoon, Khlaisang, & Koraneekij, 2015). When students start playing a game, they feel that they have the ability to finish the game tasks. However, if the underlying mathematical task is overly difficult for them, their continued play will not be productive in terms of mathematics learning. In such a situation, teacher scaffolding, which is provided in the game-based learning environment, can maintain students' interest and engagement in a way that continues to produce the desired learning (Barzilai & Blau, 2014; Chen & Law, 2016; Haataja et al., 2019).

According to Barzilai and Blau (2014), scaffolding can help students build a link between the knowledge learned in the game and subject knowledge. Watson et al. (2011) elaborated that teachers serve as a guide in digital game-based learning as they structure the game task, reduce the complexities, make thinking strategies explicit, and direct students' attention toward the learning outcomes (Haataja et al., 2019). Meanwhile, students have the opportunity to proceed in a deeper manner, control their problem-solving learning process, and achieve their learning goals (Barzilai & Blau, 2014; Rienties et al., 2012; Waiyakoon et al., 2015). Chen and Law (2016) suggested that scaffolding in digital game-based learning could provide adaptive and sufficient amounts of support that would not only help in determining students' learning needs but also improve their learning processes. In addition to making learning more accessible to students, a teacher who provides guidance and encouragement—by asking students questions and allowing them to share their knowledge and experiences—can positively influence their emotions toward learning and lead to their persistence in learning, even in the face of difficulties (Barzilai & Blau, 2014; Chen & Law, 2016; Rienties et al., 2012; Muhonen et al., 2016). In this study, teacher scaffolding was provided in digital game-based learning in mathematical classrooms to examine whether the integration of teacher scaffolding and digital games can influence students' learning in primary mathematics.

2. Aim and research questions

The current study explores the ways in which teacher scaffolding is provided in digital game-based learning in primary mathematics classrooms and the effects of students' perceptions of learning in a digital game in which teacher scaffolding was provided. Specifically, we attempt to answer the following research questions:

1. How can students' digital game-based learning in primary mathematics classrooms be scaffolded?
2. How does teacher scaffolding in digital games influence students' mathematics learning?

3. Methods

3.1. Context and participants

The data presented in this study were collected from five mathematics classrooms, including statistics on students and teachers, covering three weeks in three primary schools in China. With the fourth author's support, the experiment was conducted in the autumn of 2018. Table 1 represents descriptions of the participating students and teachers.

Table 1. *Description of participants*

Schools	**Number of participants**	
	Students (S)	**Teachers (T)**
School A (Grade 4)	• Class 1: N = 36 • Class 2: N = 37	• Class 1: Teacher 1 • Class 2: Teacher 1
School B (Grade 5)	• Class 1: N = 21 • Class 2: N = 20	• Class 1: Teacher 2 • Class 2: Teacher 3
School C (Grade 4)	• Class 1: N = 27	• Class 1: Teacher 4
Total	**141**	**4**

Note: School A decided that the same mathematics teacher (Teacher 1) would scaffold both Class 1 and Class 2.

The participating students (age 9–11; boys N = 77, girls N = 64) had experience learning mathematics through games (e.g., playing cards) in their schools. However, they did not have learning experience with digital games in mathematics prior to the experiment. The participants also included four Chinese mathematics teachers, all of whom (Teacher 1–Teacher 4) were female and had no teaching experience with digital games prior to the experiment.

3.2. Research design

The participating schools provided tablets for the participants. The research design is shown in Figure 1.

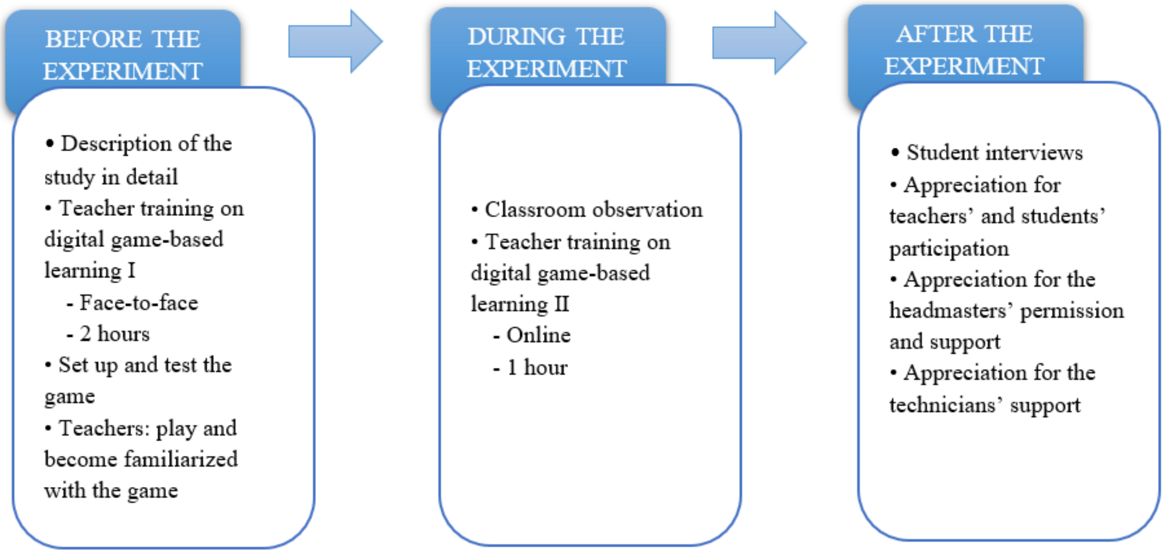

Figure 1. Process of the experiment.

A meeting was held in School A prior to the experiment. The first author presented information regarding the study (e.g., background, aims, methods, digital game-Wuzzit Trouble, schedule, etc.) to the teachers and headmasters. Teacher training on game-based learning was offered by the first author before and during the experiment. The training contents before the experiment included pedagogical activities for teachers in game-based learning, the definition and process of scaffolding, and scaffolding in the different phases of game-based learning. The training during the experiment was to provide practical scaffolding strategies based on the problems observed in the current digital game-based learning classrooms. In addition, the first author worked in the classrooms, making it possible to collect detailed observational data. Student interviews were conducted at the end of the experiment. The fifth author provided a digital game application called Wuzzit Trouble, which was used in the experiment (Figure 2).

Figure 2. The Wuzzit Trouble game interface.

Wuzzit Trouble is a tablet-based mathematics game available through the iTunes App Store and Google Play. "Wuzzits" are variously colored creatures that have been trapped in the cages of a castle (Author, 2015b; Pope & Mangram, 2015). The goal of the game is to free Wuzzits by obtaining all the keys. Wuzzit Trouble has a three-level structure of difficulty; there are 25 integer-arithmetic problems within each level; and new players have to start from the first level (Author, 2015b). Players need to rotate one or more small cogs so as to move the large gear wheel, which can cause the keys to move, and finally reach the keys (Author, 2015b). For example, in Figure 2, three keys are located at numbers 8, 46, and 60 on the large gear, and there are three cogs (4, 6, and 10). In order to reach the key located at number 46, we can tap and turn cog 10 four times to the right and tap and turn cog 6 once to the right to reach that key. When playing Wuzzit Trouble, players need to decide which direction to move the cog, and which key they should pick first (Pope & Mangram, 2015). Most integer-arithmetic problems have more than one solution, and various numbers of stars (one, two, or three) and points can be obtained by releasing Wuzzits with fewer rotations (Author, 2015b; Pope & Mangram, 2015). It should be pointed out that, during gameplay, no problem-solving support or feedback is given on the interface. Therefore, teacher scaffolding can be beneficial for students when they play Wuzzit Trouble in mathematics learning.

3.3. *Data collection*

Qualitative data were collected throughout the experiment via classroom observations and student interviews. A description of the data-collection methods is provided in Table 2.

Table 2. *Description of the data-collection methods*

Methods	**Description of data collection**
Observation	• Five classes (students: N = 141; teachers: N = 4) were observed by the first author • The observational process lasted ten school days • Observational content: teachers' scaffolding activities in the orientation and gameplay phases

Interview	• Thematic interviews with students (N = 25) conducted by the first author at the end of the experiment
	  o School A: 10 students in Grade 4 (boys: 6, girls: 4)
	  o School B: 10 students in Grade 5 (boys: 7, girls: 3)
	  o School C: 5 students in Grade 4 (boys: 3, girls: 2)
	• Two in-depth interview questions
	  o Question one: Did your mathematics teacher scaffold you in the game-based learning process? If yes, how? If no, what was the teacher doing at that time?

	○ Question two: Do you think that teacher scaffolding is helpful for you to learn mathematics? If yes, why? If no, why?

The schools organized an after-school activity for the experiment so that the participating students and teachers could use Wuzzit Trouble in the classrooms. In each after-school activity, the students used Wuzzit Trouble to practice and solve integer-arithmetic problems, and the teachers provided scaffolding when needed. The activity lasted approximately 25 minutes each day. Five classes were observed in the experiment, and the first author collected observational data over ten school days. The observational data involved teacher scaffolding in the phases of orientation and gameplay. Scaffolding during orientation included introducing background information and the gaming process and familiarizing students with the game and learning goals. During the gameplay, scaffolding included dialogic interaction, in-time instruction, adaptive support, encouragement, etc.

At the end of the experiment, interviews were conducted by the first author. Twenty-five students were randomly selected by their mathematics teachers to participate in personal thematic interviews. Each interview lasted approximately five minutes and was conducted in an empty classroom. The students were required to present their perspectives and opinions in greater depth according to their learning experience in the ten-school-day digital game-based learning environment. The first four authors determined the areas of questioning for the interviews in advance, including reflections on the teacher scaffolding in digital game-based mathematics learning; 195 student answers (as sentences) were acquired, and all interviews were recorded. The language used in the data collection was Chinese. The analysis was conducted in the original language, and the excerpts included in this article were translated by the first author.

3.4. Data analysis

The interview data were analyzed in three stages. In the first stage of the analysis, the dataset was transcribed with a web application and then consolidated and organized by the first author. The entire dataset was analyzed using qualitative content analysis (Mayring, 2014).

In the second stage, the analysis began with a data overview in which all responses were identified as the participants' viewpoints and opinions, without differentiating between them (Table 3). We found 100 related quotations that could be considered descriptions and reflections related to teacher scaffolding in the digital game-based learning environment.

Table 3: *An example of a student's responses*

Question two: Do you think that teacher scaffolding is helpful for you to learn mathematics? If yes, why? If no, why?		
Student number	**Yes/No**	**Responses**
8	Yes	• R1: Master mathematical knowledge • R2: Improve interest in mathematics • R3: Get good achievement in mathematics • R4: Because arithmetic skills are facilitated, daily life is also influenced, e.g., shopping in supermarkets

In the third stage, we classified the quotations into content categories using an open-coding procedure to find the data categories (Figure 3). The first cycle of this stage produced 18 subcategories, which were sorted into two main categories. The subcategories were again reviewed with further integration, so our final classification consisted of seven subcategories within two categories: One was the process behind the one-to-one scaffolding, which included four subcategories, and the other contained reflections on teacher scaffolding, which included three subcategories.

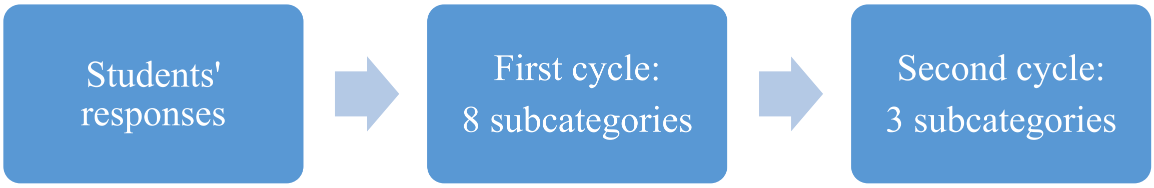

Figure 3. Classification and integration steps in the second category.

The classroom observations were not transcribed, but the first author made notes of key classroom events, such as "scaffolding moments," which described what kinds of teacher scaffolding were used and how interactional situations occurred in the digital game-based learning environment. These scaffolding moments were then sorted according to the phases (orientation and/or gameplay) in which they occurred in the classroom and were then used to support the findings from the interviews.

4. Results

4.1. Teacher scaffolding strategies

The first research question of the study was to identify how teachers scaffold students' digital game-based learning in primary mathematics classrooms. The observations highlighted the teacher scaffolding provided in the orientation and gameplay phases, respectively. Two scaffolding strategies were identified through classroom observations and the student interviews (Figure 4).

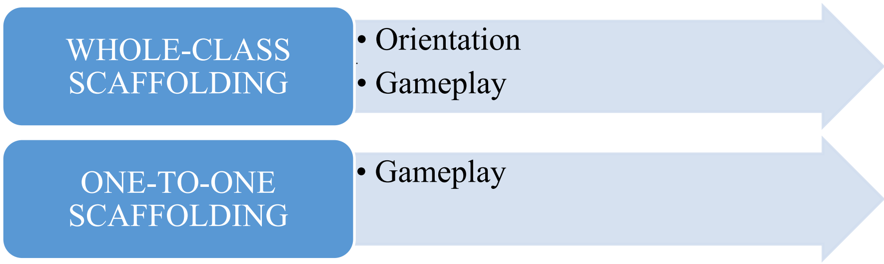

Figure 4. Strategies of teacher scaffolding.

4.1.1. Whole-class scaffolding

Whole-class scaffolding occurred in both the orientation and gameplay phases. Scaffolding in the orientation phase involved introducing the background information of the game, demonstrating the gaming process, illustrating the goals of the game, and familiarizing students with the game. Most students listened to the teachers, and some of them asked relevant questions about the game. During the observations, it was clear that the students had a preference for digital games in practicing and solving integer-arithmetic problems in mathematics and that the atmosphere of the classrooms was active and lively. The results revealed that the teachers' classroom organizing strategies (e.g., locked tablet screens, stopped teaching, clapped hands, etc.) played an important role in whole-class scaffolding in the digital game-based learning environment.

Following the orientation phase whole-class scaffolding also occurred in the first few days of gameplay. The main reason for this was that the teachers had found that most students were experiencing difficulty with similar types of problems. The students stated that:

> Generally, [the mathematics teacher] presented the problem in the digital game on the smartboard. She taught us how to analyze the problem and wrote down methods and steps for solving [problems] on the blackboard. (Student 15)
>
> For example, there was a difficult problem, and most of us could not solve it. She [the mathematics teacher] would present that problem on the smartboard or blackboard and

then instruct us as to how to analyze and solve it. She also asked students who understood well to share their [steps for solving the problem]. (Student 8)

The results showed that whole-class teacher scaffolding enabled congruity between most students' level of experience and conceptual understanding, which helped determine the students' learning needs in a clear and in-depth manner. The students then became familiar with the gaming process and were able to control their problem-solving in a deeper manner during their learning with the digital game.

4.1.2. One-to-one scaffolding

One-to-one scaffolding occurred during the gameplay phase. When an individual student could not solve the problem independently, teacher's in-time instruction and adaptive support were provided. The results revealed that one-to-one teacher scaffolding included recognizing students' difficulties, providing relevant clues and suggestions, directing students to see the important points, offering more detailed information, focusing students' attention on the learning content, etc. (Kangas et al., 2017; Nousiainen et al., 2018; Van de Pol, et al., 2010). Based on the analysis of the students' interview responses, the processes underlying the one-to-one scaffolding are summarized in Figure 5.

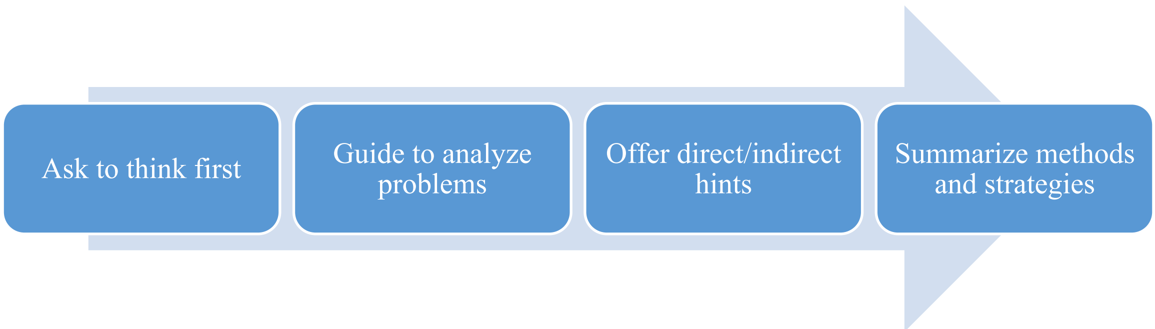

Figure 5. Processes of the one-to-one scaffolding in gameplay.

All the student interviewees stated that the teachers did not give them the answers directly but instructed them to think and analyze the problems through dialogue (e.g., ask questions);

they then provided hints when necessary and summarized the methods and steps for solving the problem when this was deemed necessary. As some students noted:

> She [the mathematics teacher] did not tell me the answer but let me think independently. Then she taught me the steps of problem solving. (Student 4)
>
> For example, multiples of the numbers. The teacher reminded me to think about what multiples were in the numbers, what relations there were between the numbers, and which number could be matched with the cog. Through this, I solved the problem and completed the task. (Student 6)
>
> When I could not solve this problem, the teacher would provide me with some hints; I felt it was very good. (Student 19)

In comparison to whole-class scaffolding, one-to-one teacher scaffolding concerned the individual student's performance. Therefore, the teachers used the above-mentioned concrete and effective scaffolding strategies to encourage the students to explore as well as to trigger their interest and help them conduct their learning independently in digital game-based learning.

Through the classroom observations and interviews, contingency, fading, and transfer of responsibility occurred and were illustrated in both the whole-class and one-to-one scaffolding strategies. The results showed that the two scaffolding strategies were suitable for use in supporting the students' learning activities in digital game-based learning in primary mathematics classrooms and that, as a result, the integration of teacher scaffolding into digital game-based learning could diagnose the students' current level of understanding and have an important effect on their learning and development in mathematics in primary education.

4.2. Influence of teacher scaffolding

The second research question was to examine the influence of teacher scaffolding on students' mathematics learning through the digital game. Teacher scaffolding in the phases of orientation and gameplay were reflected in the students' comments during the interviews (Figure 6). The perception of teacher scaffolding in terms of digital game-based learning in developing arithmetic skills, activating interest in mathematics, and encouraging exploration was judged by the students in the interviews.

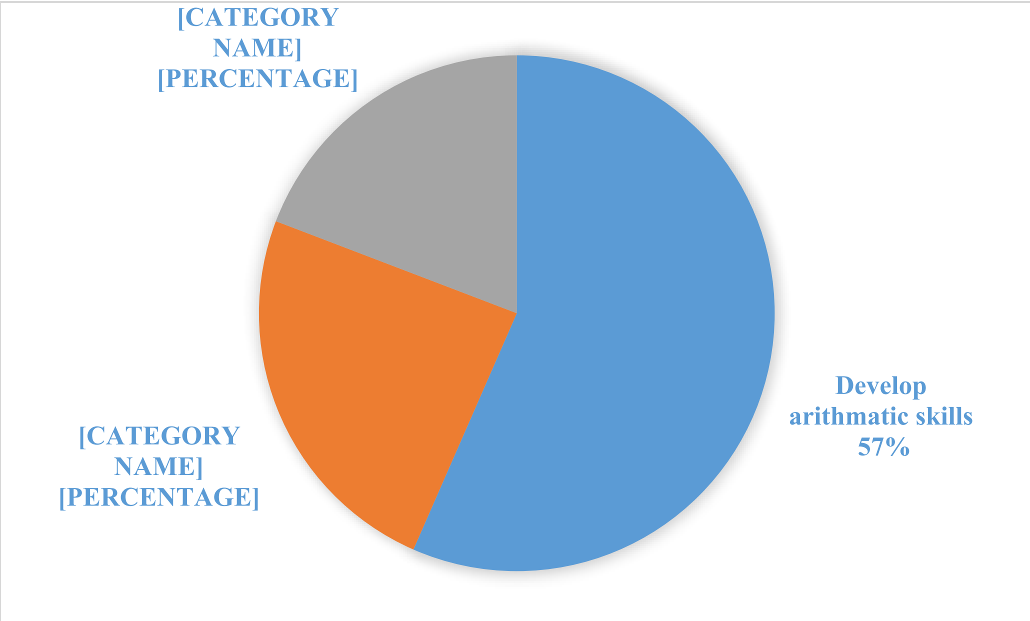

Figure 6. Students' (N = 25) reflections on teacher scaffolding in both the orientation and gameplay phases.

Fifty-seven percent of the students agreed that the teachers' adaptive support and in-time instructions helped them understand the content knowledge and improve their mathematical thinking ability, which give them the opportunity to proceed and control their problem-solving learning process. For example, some students commented that:

> It [the teacher's instruction] could open my mind, which stimulated me into not thinking only about one point but thinking about many points. (Student 7)
>
> Because when I mastered the solving methods [with the teacher's support], I could learn by analogy and solve more problems. (Student 22)

> If you did not know the solving methods, you could not solve the problem. You would be irritable and feel bad. So, the result was to dislike mathematics and refuse to do [mathematical problems]. (Student 9)

Approximately 24% of the students reported that the teachers' tutoring activated their interest in mathematics to a higher level and increased their willingness to learn mathematics. One student stated that the teacher's support "made us like mathematics more. I was more interested in mathematics" (Student 14). Another student noted how the teacher's support "made me enjoy mathematics consistently" (Student 12).

Nineteen percent of the students also reported that the teachers' encouragement affected their emotions, stimulating them to think independently and explore, despite difficulties. As Student 23 reflected, "When I could not solve the problem, I would give up after thinking for a while. But the teacher's encouragement inspired me to explore persistently." Student 2 reflected, "Some classmates do not like to learn mathematics if there is no teacher encouragement. However, when receiving encouragement, they like learning better."

According to the results, teacher scaffolding has an important effect on students' learning activities with digital games in mathematics. Adaptive support and intervention were conducive for students to connect the knowledge learned in the digital games with the subject knowledge, enabling them to understand related content, practice, and solve integer-arithmetic problems. Meanwhile, the teachers' tutoring and encouragement increased the students' interest in mathematics, creating an environment for the students to more easily explore and making thinking and strategies explicit. Therefore, they were willing to solve integer-arithmetic problems. Furthermore, teacher scaffolding in digital game-based learning was useful in terms of activating the students to interact with the learning environment and focus on specific content knowledge, thus affecting their learning outcomes in mathematics in primary education.

5. **Conclusion and discussion**

This study aimed to describe and explore the ways in which teacher scaffolding is provided in digital game-based learning and the effects of students' perceptions of mathematics learning in a digital game in which teacher scaffolding was provided. Two approaches to teacher scaffolding were identified in the study—whole-class and one-to-one scaffolding—both of which had an impact on students' knowledge learning, arithmetic skills, and interest development in mathematics. These results are important, as they contribute toward addressing the gap in previous knowledge by highlighting the various strategies of teacher scaffolding and describing means of sustaining effective scaffolding in digital game-based learning in primary education.

Our first research question focused on the kinds of teacher scaffolding strategies provided in digital game-based learning in primary mathematics classrooms. The results showed that, first, both the whole-class and one-to-one scaffolding approaches were identified from the data, and second, each scaffolding approach was distinguishable in the different phases (orientation and/or gameplay). The analyses indicated that whole-class scaffolding was significant in the orientation phase and during the first few days of gameplay when the students began practicing and solving integer-arithmetic problems in the digital game-based learning environment. Whole-class scaffolding was directed by specific strategies espoused by teachers who played the role of leaders (Muhonen et al., 2016). When individual students proceeded to solve integer-arithmetic problems with digital games, the interactive dialogues were more balanced between the students and teacher, and the teacher's role became that of a tutor and guide who supported and instructed individual students via one-to-one scaffolding (Kangas et al., 2017; Nousiainen et al., 2018; Watson et al., 2011).

Moreover, the findings of this study suggest that teachers' classroom management strategies play an important role in ensuring the success of the scaffolding strategy, especially in relation to whole-class scaffolding in the digital game-based learning environment. In addition, technological tools, such as smartboards and slide projectors, used by the teachers can ensure that scaffolding is available and beneficial to every student who needs it (Kangas et al., 2017; Nousiainen et al., 2018).

Our second research question focused on the influence of teacher scaffolding in students' mathematics learning using a digital game in primary education. The findings indicated that the three steps of scaffolding were closely intertwined and had an impact on the students' knowledge learning and arithmetic skill development in primary mathematics classrooms. In our study, the teachers provided questions, diagnoses, explanations, instruction, and hints that were contingent on the level of individual students (Kangas et al., 2017; Tropper et al., 2015; van de Pol et al., 2010; Wood et al., 1976); support was gradually withdrawn when the teachers found that the students could independently solve integer-arithmetic problems with digital games; and in the end, when the students proceeded to a higher level with the digital game, no support was needed or provided, and the students were deemed responsible for their own learning (Muhonen et al., 2016; Tropper et al., 2015; van de Pol et al., 2010).

Additionally, teacher scaffolding was found to encourage the students to independently explore and activate their interest in mathematics. When they had trouble with integer-arithmetic problems, they experienced anxiety and helplessness, which led to difficulties in digital game-based learning. However, the teachers' in-time support and direction helped the students achieve greater energy and confidence, which was useful for learning content knowledge with a digital game in primary classrooms (Barzilai & Blau, 2014; Rienties et al., 2012). The analyses indicated that students' assessments of their mastery of mathematical knowledge and arithmetic skills increased their interest in mathematics. Thus, teacher scaffolding in digital game-based learning effectively served the students by developing and deepening their knowledge building and learning outcomes in mathematics (Barzilai & Blau, 2014; Muhonen et al., 2016). The findings of the study showed that in a digital game-based learning classroom, mathematics teachers transformed from traditional teachers into tutors and guides who support and instruct students in their learning process (Kangas et al., 2017; Nousiainen et al., 2018; Watson et al., 2011). This transformation allowed the students to experience and explore mathematics knowledge, activate their interest in mathematics, and develop their content understanding and arithmetic skills (Bakker et al., 2016; Chang et al., 2016; Drijvers et al., 2014; Meletiou-Mavrotheris & Prodromou, 2016; Author, 2018).

The current study does have limitations, for example, little was known about how teachers scaffold students in traditional mathematics classrooms. Also, the language of the data was translated from Chinese to English by the first author, since only the first author was involved in the whole data-collection process. In addition, because of the authors' personal schedules, they were not present at the parents' meetings to describe the study to the parents.

Nevertheless, even if the data are specific to these schools and students, and the study focused on capturing the experience of teacher scaffolding in digital game-based learning in primary mathematics classrooms, the explanations and conclusions are useful for understanding how other students engage in digital game-based learning environments where teacher scaffolding is provided (Nousiainen et al., 2018). While the study concentrated on mathematics education, the influence found herein in relation to teacher scaffolding can also be found in other educational contexts. Integrating teacher scaffolding into digital game-based learning can be applied to other subjects in school education.

Furthermore, the results of the study point to implications for teachers and teacher education in digital game-based learning. On one hand, the set of scaffolding strategies could be summarized and listed based on the students' perceptions regarding digital game-based learning, which included support of students' knowledge learning and arithmetic skills (questions, diagnosis, hints, instruction, explanation, and summary) and support of r their motivation and emotion (guidance, control of frustration, and encouragement). On the other hand, the findings of the study suggest that teachers can variously design and develop ways in which to integrate scaffolding into digital game-based learning environments, such as for the whole class or for individual students, for high-participating students or low-participating students, with or without technological tools, etc.

This study sought to identify different approaches to teacher scaffolding and the correlated influence on mathematics in a digital game-based learning environment. Future research should probe additional scaffolding approaches and examine which scaffolding characteristics may effectively facilitate learning through the use of digital games. There is a need for further studies exploring the manner in which teachers' competencies can develop alongside the integration of digital games into daily teaching.

The study followed the ethical guidelines of the Finnish Advisory Board on Research Integrity (2012). When conducting research with children, ethical issues need to be considered (Dalli & Te One, 2012; Einarsdóttir, 2007). As Einarsdóttir (2007) pointed out, informed consent, confidentiality, interactions, and protection are important ethical matters in all research, especially in research with children. In this study, while written while written informed consent was not obtained, the headmasters involved did use a parents' meeting to inform the children's parents both about the experiment and their children's participation. The children understood that their participation was voluntary and that they were free to withdraw at any time (Einarsdóttir, 2007). Both anonymity and confidentiality were guaranteed in the study. The participants' names were anonymized in the study, and all the data were stored on a password-protected mobile hard drive accessible only to the first author.

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References

Bakker, M., van den Heuvel-Panhuizen, M., & Robitzsch, A. (2016). Effects of mathematics computer games on special education students' multiplicative reasoning ability. *British Journal of Educational Technology, 47*(4), 633–648.

Barkatsas, A. T., Kasimatis, K., & Gialamas, V. (2009). Learning secondary mathematics with technology: Exploring the complex interrelationship between students' attitudes, engagement, gender and achievement. *Computer & Education, 52*, 562–570.

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computer & Education, 70*, 65–79.

Chang, M., Evans, M. A., Kim, S., Norton, A., Deater-Deckard, K., & Samur, Y. (2016). The effects of an educational video game on mathematical engagement. *Education and Information Technologies, 21*, 1283–1297.

Chen, C.-H., & Law, V. (2016). Scaffolding individual and collaborative game-based learning in learning performance and intrinsic motivation. *Computers in Human Behavior, 55*, 1201–1212.

Chen, M.-P., Wong, Y.-T., & Wang, L.-C. (2014). Effects of type of exploratory strategy and prior knowledge on middle school students' learning of chemical formulas from a 3D role-playing game. *Educational Technology Research and Development, 62*, 163–185.

Drijvers, P., Doorman, M., Kirschner, P., Hoogveld, B., & Boon, P. (2014). The effect of online tasks for algebra on student achievement in grade 8. *Technology, Knowledge and Learning, 19*, 1–18.

Author, 2018 [details removed for peer review]

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry, 12*(2), 219–245.

Haataja, E., Moreno-Esteva, E. G., Salonen, V., Laine, A., Toivanen, M., & Hannula, M. S. (2019). Teacher's visual attention when scaffolding collaborative mathematical problem solving. *Teaching and Teacher Education, 86*, 1–15.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127.

Huang, Y. M., Huang, S. H., & Wu, T. T. (2014). Embedding diagnostic mechanisms in a digital game for learning mathematics. *Educational Technology Research and Development, 62,* 187–207. doi:10.1007/s11423-013-9315-4

Iten, N., & Petko, D. (2016). Learning with serious games: Is fun playing the game a predictor of learning success? *British Journal of Educational Technology, 47*(1), 151–163.

Kangas, M., Koskinen, A., & Krokfors, L. (2017). A qualitative literature review of educational games in the classroom: The teacher's pedagogical activities. *Teachers and Teaching, 23*(4), 451–470. doi:10.1080/13540602.2016.1206523

Author, 2018 [details removed for peer review]

Author, 2018 [details removed for peer review]

Krapp, A. (2002). An educational-psychological theory of interest and its relation to self-determination theory. In E. L. Deci & R. M. Ryan (Eds.), *Handbook of self-determination research* (pp. 405–427). Rochester, NY: Rochester University Press.

Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning and development. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 3–25). Hillsdale, NJ: Erlbaum.

Luhan, J., Novotna, V., & Kriz, J. (2013). ICT support for creative teaching of mathematics disciplines. *Interdisciplinary Studies Journal, 2*(3), 89–100.

Makar, K., Bakker, A., & Ben-Zvi, D. (2015). Scaffolding norms of argumentation-based inquiry in a primary mathematics classroom. *ZDM Mathematics Education, 47*, 1107–1120.

Mayring, P. (2014). Qualitative content analysis: Theoretical foundation, basic procedures and software solution. Klagenfurt. URN. Retrieved from http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173

Meletiou-Mavrotheris, M., & Prodromou, T. (2016). Pre-service teacher training on game-enhanced mathematics teaching and learning. *Technology, Knowledge and Learning, 21*(3), 379–399.

Muhonen, H., Rasku-Puttonen, H., Pakarinen E., & Poikkeus, A.-M. (2016). Scaffolding through dialogic teaching in early school classrooms. *Teaching and Teacher Education, 55*, 143–154.

Nousiainen, T., Kangas, M., Rikala, J., & Vesisenaho, M. (2018). Teacher competencies in game-based pedagogy. *Teaching and Teacher Education, 74*, 85–97.

Pata, K., Sarapuu, T., & Lehtinen, E. (2005). Tutor scaffolding styles of dilemma solving in network-based role-play. *Learning and Instruction, 15*, 571–587.

Pope, H., & Mangram, C. (2015). Wuzzit Trouble: The influence of a digital math game on student number sense. *International Journal of Serious Games, 2*(4), 5–22.

Reeve, J., Lee, W., & Won, S. (2015). Interest as emotion, as affect, and as schema. In K. Renninger, M. Nieswandt, & S. Hidi (Eds.), *Interest in mathematics and science learning* (pp. 79–92). Washington, DC: American Educational Research Association. Retrieved from http://www.jstor.org/stable/j.ctt1s474j0.10

Renninger, K. A., & Bachrach, J. E. (2015). Studying triggers for interest and engagement using observational methods. *Educational Psychologist, 50*(1), 58–69.

Renninger, K. A., & Hidi, S. (2011). Revisiting the conceptualization, measurement, and generation of interest. *Educational Psychologist*, *46*(3), 168–184.

Rienties, B., Giesbers, B., Tempelaar, D., Lygo-Baker, S., Segers, M., & Gijselaers, W. (2012). The role of scaffolding and motivation in CSCL. *Computer & Education, 59*, 893–906.

Author, 2017 [details removed for peer review]

Author, 2018 [details removed for peer review]

Tropper, N., Leiss, D., & Hänze, M. (2015). Teachers' temporary support and worked-out examples as elements of scaffolding in mathematical modeling. *ZDM Mathematics Education, 47*, 1225–1240.

Van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher-student interaction: A decade of research. *Educational Psychology Review, 22*(3), 271–296. doi:10.1007/s10648-010-9127-6

Vandercruysse, S., Vandewaetere, M., Cornillie, F., & Clarebout, G. (2013). Competition and students' perceptions in a game-based language learning environment. *Educational Technology Research and Development, 61*, 927–950.

Waiyakoon, S., Khlaisang, J., & Koraneekij, P. (2015). Development of an instructional learning object design model for tablets using game-based learning with scaffolding to enhance mathematical concepts for mathematic learning disability students. *Procedia-Social and Behavioral Sciences, 174*, 1489–1496.

Watson, W. R., Mong, C. J., & Harris, C. A. (2011). A case study of the in-class use of a video game for teaching high school history. *Computers & Education, 56*, 466–474.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*, 89–100. doi:10.1111/j.1469-7610.1976.tb00381.x

Yin, R. K. (2013). *Case study research: Design and methods* (3rd ed.). Thousand Oaks, CA: Sage.